A SPARK-CHAMBER SYSTEM WITH VERY LARGE HYDROGEN TARGETS FOR NEUTRINO EXPERIMENTS: PRELIMINARY TECHNICAL CONSIDERATIONS

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1. Need for Larger Hydrogen-Containing Systems.

Present plans for the study of neutrino interactions in hydrogen center around the proposed 25-ft hydrogen bubble chamber. The volume of that chamber is 100 m^3 (7 metric tons), of which perhaps 70 (5 tons) constitute the useful fiducial volume. When and if constructed, it will be by far the largest bubble chamber ever built. Its size presents very great difficulties; there is considerable doubt among the experts as to how well it will work, and even some residual fear that perhaps it may not work at a satisfactory level at all.

Mammoth though it may appear, in at least one sense the chamber is too small. This became clear in the course of the 1968 summer study when attention was turned to the rate at which useful data will be accumulated and the amount of accelerated beam necessary to obtain useful data. Considering the available neutrino flux and the expected cross sections, the chamber is not large enough to minimize the data cost, that is, the sum of the accelerator time cost and the bubble chamber operating cost for a given number of events. Since the accelerator cost is dominant, a larger detector is required; but in the

present state of bubble chamber technology one does not dare to take a

larger step than the present one even assuming no financial limitations.

As matters stood in the 1968 summer study, the total neutrino event

rate in the chamber even with rather optimistic assumptions about

focusing essentially the entire neutrino spectrum into a beam, would

not exceed 0.5 events per pulse. Of these events, about half will result

from neutrinos of 5 GeV or less. Studies on events produced by neu-

trinos of, say, 10 GeV or more will yield a total rate of 0.1 per pulse.

Antineutrino events will be down by another factor of 3 to 10. In his

report,Snow[1] estimated that 10^5 or more pulses would be needed to do

a "minimal" experiment on elastic neutrino interactions and 2.5×10^6

for a minimal experiment on recoil proton polarization (these are with

a deuterium target). For hydrogen, the corresponding antineutrino

elastic experiment, if one requires the scattered neutron to be detected,

requires 2.5×10^6 pictures even without polarization measurements.

To do the antineutrino production of lambdas, it takes 2.5×10^6 pictures

to obtain 1000 visible lambda events in each of five momentum bins.

A 2.5-million picture experiment probably represents at least half

a year's operation of the accelerator with the bulk of the beam going

to produce neutrinos. A year's operation of the accelerator costs about

$40 million (excluding new equipment), and of the bubble chamber about

$4 million. It seems worthwhile, therefore, to reexamine the possi-

bilities of designing neutrino detection systems that use spark chambers

and very large but relatively inexpensive hydrogen targets. Although

such systems have been suggested,[2] no extended discussion of the

attendant problems seems to exist. This may be due in part to the

conceptual difficulties of designing an adequate system and in part to

the lack of a good case for the physics that such a system would make

accessible. As a first approximation, let us take Snow's figures as

representing such a prima facie case and turn our attention to spark-

chamber technology to see whether it is equal to the task.

2. Specifications.

We define the design objective as a system using hydrogen targets

with thin walls in which reconstruction of vertices in hydrogen will be

sufficiently accurate to allow kinematic reconstruction; in which the

variation of sensitivity with track direction (anisotropy) is not great

enough to seriously affect the data; in which it should at the very least

be possible to identify muons and electrons and hopefully other particles

as well; and to detect recoil neutrons. In addition, we consider it

highly desirable that the system be modular so that a small working

system can be tested that will allow eventual expansion to the 100-ton

size which bubble chambers are unlikely to reach and which would make

possible the exploration of many processes otherwise inaccessible. The

system should be capable of attacking from the beginning a reasonably

large area of neutrino physics and consequently will require good event-

recognition capabilities.

To meet the above design objectives, several system characteristics become immediately apparent. The spark-chamber detectors must operate in thermal and hydrostatic equilibrium with the liquid hydrogen; otherwise there will be severe heat-loss problems, as well as relatively massive walls in inconvenient locations. The chambers and targets must necessarily have large areas, otherwise the requisite quantities of hydrogen cannot be accommodated. In order to reduce the volume of the system and consequently of the magnetic field required to determine momenta, the sum of spark-chamber volume plus target volume must be kept to a minimum. To avoid losing events, the targets ought to be reasonably thin. The heat load imposed by the thermal dissipation of spark energy must be tolerable. The design study must interpret these requirements quantitatively.

No data exist on the operation of spark chambers at liquid-hydrogen temperature, and this lack must certainly be remedied before serious design work can be undertaken. However, data do exist at high pressures (to 30 atmospheres) and at temperatures down to liquid nitrogen.[3-5] The results are encouraging; the behavior (efficiency, delineation) improves with increasing density as expected. Because of higher density and lower thermal velocity the diffusion of electrons in the gas should be slower (about as $T^{1/2}$) than at room temperature, and so the limiting intrinsic accuracy of delineation should improve. Streamer chambers should also work better and give more light in these circumstances.

With this in mind, let us start by postulating as a point of departure

for further study a system consisting of modules, each constructed as

shown in Fig. 1. The liquid-hydrogen target module, about 3 meters

square and 11 cm (0.7 gm/cm^2) thick, contains a cubic meter and is

made of mylar (or equivalent material) a few mils thick. To keep it

flat, it is made like a sofa pillow with internal threads and button seals.

The only pressure on the mylar is the hydrostatic pressure of the liquid

hydrogen since the target is surrounded by helium (or He-Ne) at atmos-

pheric pressure. At liquid-hydrogen temperature, the helium density

is 15 times atmospheric. Consequently, spark-chamber gaps operated

in this gas will have the efficiency and delineation characteristics of

much wider gaps at room temperature; this has been verified for high-

pressure room-temperature gas. Thus, even a one-cm gap should give

good track delineation, and the lower limit on gap width will probably

be imposed by optics. The module of Fig. 1 may therefore be any com-

bination of wide-gap (i.e., 1 cm or more), streamer or digital sections,

each with gaps that need not be much more than a cm thick. In particu-

lar, the streamer mode with higher-density gas should produce brighter

tracks and would guarantee isotropic detection efficiency when that is

important.

Technical points that come to mind include the following. The use

of streamer-mode operation is favored over wide-gap from a thermal-

load standpoint; less heat is produced in the discharge although the heat

load, ~ .01 joule per gap, is tolerable even for wide gaps. High-voltage leads must be brought into the low-temperature, vacuum-insulated volume. The spark-chamber gas must be completely free of oxidants. The entire chamber system needs a transverse magnetic field of 20 kg or more. Optical access is not easy; in some experiments, modules can be made with digitized planes to avoid optical access.

The hydrogen target modules are thin (0.7 g/cm^2) to allow slow particles to emerge and to simplify vertex reconstruction by decreasing the distance that tracks need to be extrapolated. The targets are, however, too thick to allow spectator protons from deuterium to be seen. One-prong events cannot be kinematically reconstructed unless the neutral secondary is detected; nonetheless, useful data may be obtained in such events. If the system is sufficiently large, containing many modules, the probability of gamma-ray conversion and neutron detection will increase substantially; the thin-target module favors low-energy proton detection and identification. With one-cubic-meter modules, fourteen modules make a ton and a five-ton system with seventy modules would have a total target thickness of 7.7 meters, about 0.8 radiation length and an overall length (with the design of Fig. 1) of about 19 meters.

The mode of streamer-chamber operation proposed is unconventional in that the chamber is viewed not along the electric field but transversely. Seen from this direction, the streamers are several mm

long and not as bright. However, most tracks will be along the neutrino

direction, thus along the electric field and the tracks will be corres-

pondingly brighter. A mixture of wide-gap and streamer modules may

be desirable.

No serious consideration has been given to the question of magnet

design. Providing a transverse field of 20 kg over hundreds of cubic

meters is too big an undertaking to treat in a few words. It is certainly

possible but will present a major design challenge.

REFERENCES

[1]G. Snow, Report 68-59, NAL 1968 Summer Study Report, Vol. 1.

[2]L. W. Jones, Berkeley Summer Study 1961, UCRL-10022, p. 217.

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[4]G. S. Akopyan et al., Instr. and Experim. Techn., May-June 1967,
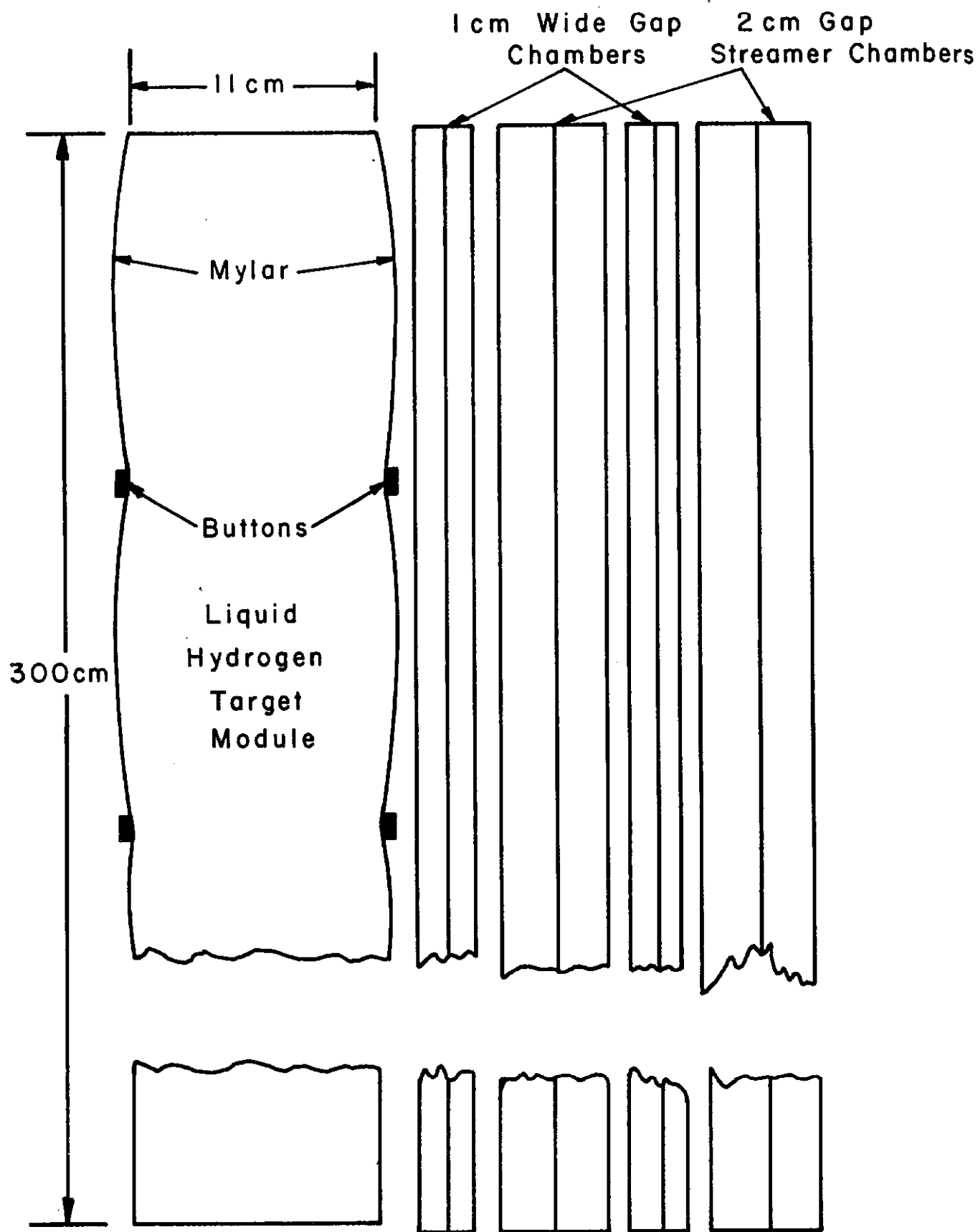   p. 517.

[5]E. F. Beall and V. Cook, unpublished report BEV770A, Nov. 8, 1962.

Fig. 1 Target-Spark Chamber Module